NASA NDE Program

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Arlington, Virginia
October 3 - 4, 2012

Outline

- Scope of NDE
- Federal Mandates
- Budget and Resource Projections
- Planning Process
- Customers
- Program Changes
- Budget Strategy
- Technical Activities & Achievements (FY12)
- Issue paper(s) FY13
- Summary

Summary of Scope of Nondestructive Evaluation

Scope of NDE Discipline

Nondestructive Evaluation (NDE) is the use of nondestructive interrogating energy to determine the integrity of systems. The activities in NDE are also listed as Nondestructive Inspection (NDI), and Nondestructive Testing (NDT).The systems may be organic or inorganic, simple and complex, and may be structural or non-structural, like wires. A real-time application of NDE in systems is called integrated structural health monitoring (ISHM). The entire electromagnetic spectrum is available for performing a NDI and ranges from direct electrical current to radio waves through microwaves, infrared, optical, ultraviolet, x-rays, through to gamma rays, as well as sound vibrations and accelerated atomic particles. Both complex bulk systems and films are characterized. The interrogated system size may vary from atomic level variations to large, meter-long, macroscopic flaws. A wide variety of instrument systems are used to make an evaluation. Familiar examples include radiographic examination, ultrasonic, liquid penetrant, or eddy current inspection. As an example of the range of NDE instruments, a visual NDI may be an accepted NDT method. In contrast, the use of neutrons to produce a 3D neutron tomographic image may also be acceptable. NDE instruments often utilize more that one spectral component to have effective NDT, and often more than one NDE instrument is applied to secure full coverage. Many flight components used in NASA's missions require adaptation of advanced NDE technologies in order to be applicable for integrity determination. Nondestructive integrity determination includes characterization of engineering properties, strain, stress, load verification, cracks, voids, inclusions, disbonds, delaminations, bonding, corrosion, erosion, constitutive components, volume fraction, orientation, impact damage, age, pressure, mass loss, mass gain, thinning, alignment, thermal diffusivity, emissivity, leaks, signature, contamination, elements, etc..

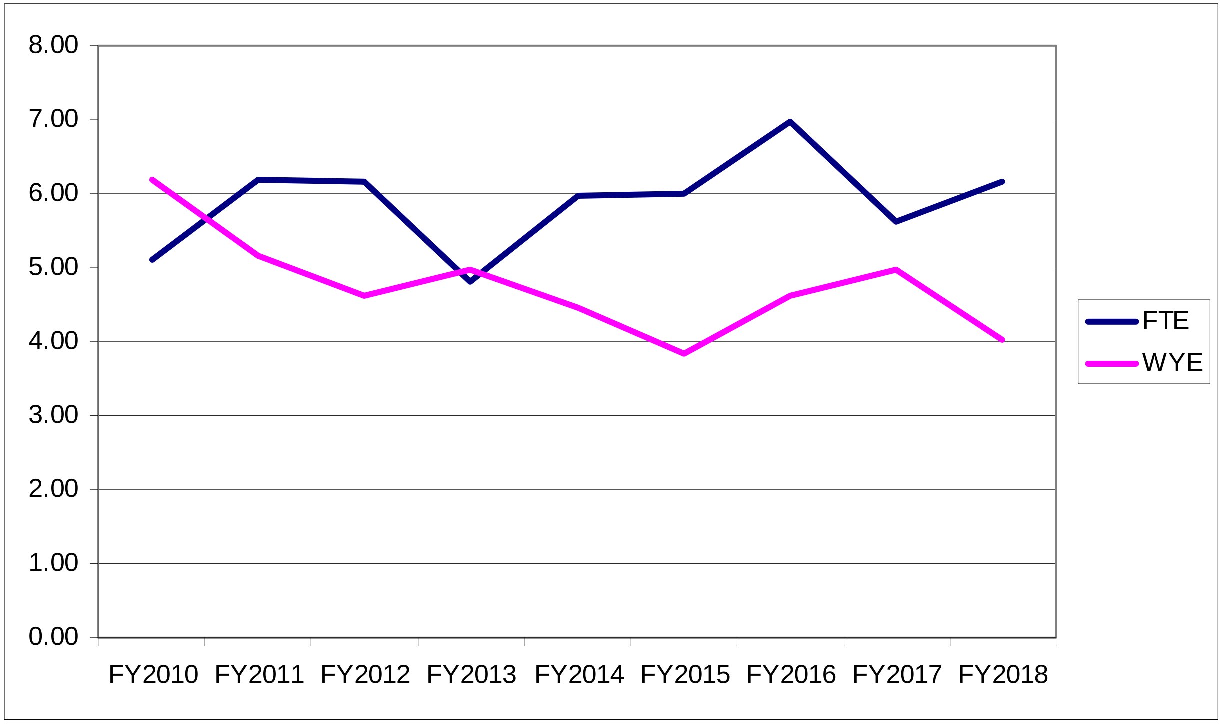
Federal Mandates Related to NDE Activities

- FAR Part 46, Quality Assurance, to ensure that contracted supplies and services comply with contract requirements
- The NASA NDE Standards, NASA-STD-5009, 2007
- The NASA Fracture Control Standards, NASA-STD-5019
- OMB Circular A–119; Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities: *The policies of OMB Circular A–119 are intended to: (1) Encourage federal agencies to benefit from the expertise of the private sector; (2) promote federal agency participation in such bodies to ensure creation of standards that are useable by federal agencies; and (3) reduce reliance on government-unique standards where an existing voluntary standard would suffice.*
- AIR FORCE SPACE COMMAND MANUAL *91-710 Vol. 3 1 July 2004, Range Safety User Requirements Manual Vol. 3 - Launch Vehicles, Payloads, and Ground Support Systems Requirements*
- NASA General Safety Program Requirements, *KNPR 8715.3*
- Space Systems-Composite Overwrapped Pressure Vessels (COPVs), July 24, 2006, *ANSI/AIAA S-081A-2006*
- NASA-STD-8719.17, *NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PV/S)*
- SPR 1740.1, *Pressure Vessel and Pressurized System Procedural Requirements*
- ASTM Pressure Vessel and Composite Standards
  - –AIAA S-080 - Space Systems Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
  - –AIAA S-081 – Space Systems Composite Overwrapped Pressure Vessels (COPVs)
  - –WK29068 New Standard — Examination of the Metallic Thin-Walled Liners in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing.
  - –WK29034 New Standard — Examination of the Composite Overwrap in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing.
  - –ASTM G114-07 Standard Practice for Aging Oxygen-Service Materials Prior to Ignitibility or Flammability Testing, *Annual Book of ASTM Standards*.
  - –ASTM E2533-09 Standard Guide for NDT of Polymeric Matrix Composites Used in Aerospace Applications, *Annual Book of ASTM Standards*.
  - –ASTM D7211-06 Standard Specification for Parts Machined from Polychlorotrifluoroethylene (PCTFE) and Intended for General Use, *Annual Book of ASTM Standards*.
  - –ASTM E2580-07 Standard Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications, *Annual Book of ASTM Standards.*
  - –ASTM E2581-07 Standard Practice for Shearography of Polymer Matrix Composites, Sandwich Core Materials and Filament-Wound Pressure Vessels in Aerospace Applications, *Annual Book of ASTM Standards.*
  - –ASTM E2582-07 Standard Practice for Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications, *Annual Book of ASTM Standards.*
  - –ASTM E 2662-09 Standard Practice for Radiologic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications, *Annual Book of ASTM Standards.*
  - –ASTM E2661-10 Standard Practice for Acoustic Emission Qualification of Plate-like and Flat Panel Composites Used in Aerospace Applications, *Annual Book of ASTM Standards.*
- Executive Office of the President of the United States, 2010 National Aeronautics National Aeronautics Research and Development Plan: *To ensure the safe flight operations of UAS, procedures for certification, licensing, training, inspection, maintenance, and operation of UAS are needed to ensure their integration into the NAS (National Aerospace System) without causing delays, reducing capacity, or com-promising safety in the air as well as on the surface. **Research in advanced manufacturing capabilities** and changes in certification processes can decrease the cost and time for the introduction of new aircraft and aircraft subsystems without compromising safety. Timely, verified results from research studies are of particular importance in the **development and allocation of requirements, standards, and criteria for certification of aircraft capabilities** and operating procedures. Despite the outstanding safety record for modern aviation, accidents still occur and safety concerns remain, including issues such as aircraft aging, sensing of vehicle health, and icing. Predicting, monitoring, and **assessing the health of aircraft, at the material, subsystem, and component level**, more efficiently and effectively. Understanding and predicting system-wide safety concerns of the airspace system and the vehicles as envisioned by NextGen, including the emergent effects of increased use of automation to enhance system efficiency and performance beyond current, human-based systems, through **health monitoring** of system-wide func-tions that are integrated across distributed ground, air, and space systems. **Aircraft-level health-management systems, including sensors and analytical tools**, will be developed that can identify problems before accidents occur. Research in **health management requires not only monitoring and detecting, but also confident prognostics** of latent potential failures before they occur. Research will also be needed for the development of improved aircraft systems and structures, physics-based prediction of material properties, and designs and **maintenance technologies to reduce material and structural failures** during operational use. Develop vehicle health-management systems to **determine the state of degradation for aircraft** subsystems. Develop and demonstrate tools and techniques to predict, **detect, and mitigate in-flight damage, degradation, and failures**. Develop reconfigurable health-managing systems for managing suspect regions in N+2 (revolutionary configurations (such as hybrid wing-body, small supersonic jets, cruise-efficient short takeoff and landing and advanced rotorcraft)) vehicles*.
- 2011 Office of the Chief Technologist (OCT) Space Technology Roadmaps: *TA13- Ground & Launch Systems Processing, Inspection, Anomaly Detection & Identification; TA02- In-Space Propulsion Technologies: Engine Health Monitoring & Safety; TA12- Materials, Structures, Mechanical Systems & Manufacturing: Nondestructive Evaluation & Sensors, Reliability / Life Assessment / Health Monitoring*
- Diaz Report (Action #23) 1/30/2004: *Develop a standard for modeling and testing (both destructive and nondestructive) of system components and assemblies.*
- McDonald Report 2/9/2000: *Identify/develop inspection technologies for aging wiring*
- *NASA NDE Working Group Charter , http://nnwg.org/index.html*
- *NASA NDE Working Group Strategic Plan, http://nnwg.org/index.html*

Budget Content - Full Cost Submission ($)

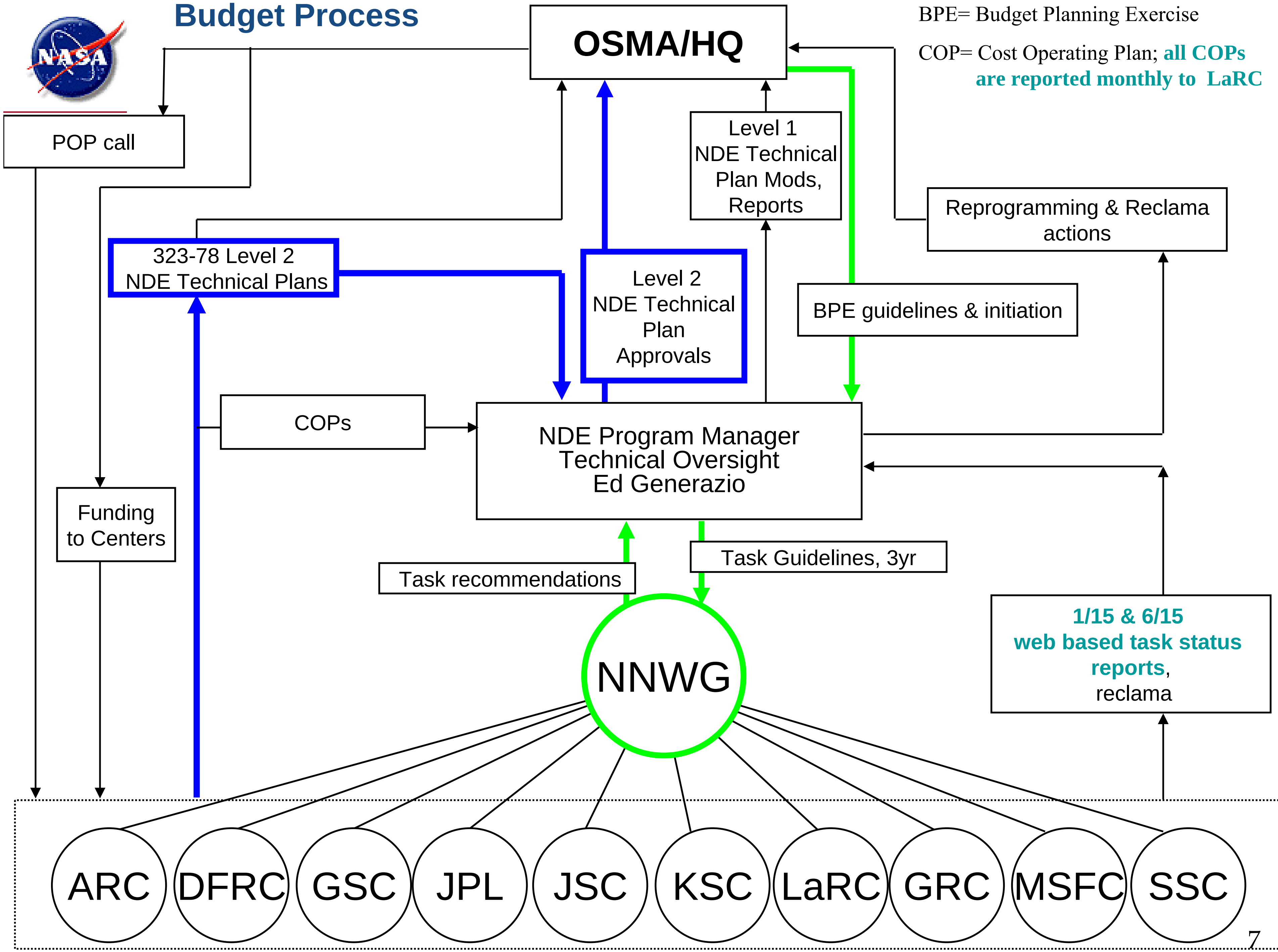
PPBE 2014 Program Review: Agency Non-Destructive Evaluation (NDE) Activity List Summary								
WBS: 724297.40.44			FY2013					
AMO-OSMA: Agency NDE Program								
Delegated Program Manager: Ed Generazio		FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
UPDATED: 4/18/2012								
In-Guide program:		2,315,291	2,440,809	2,473,009	2,548,942	2,172,484	2,258,029	2,482,604
Delegated Program or								
SMA Director's Budget								
Variable Project		**0**	**0**	**0**	**0**	**0**	**0**	**0**
Core Program		**2,315,291**	**2,440,809**	**2,473,009**	**2,548,942**	**2,172,484**	**2,258,029**	**2,482,604**

Planned Workforce (FTE & WYE)



- FTE level to meet requirements has been constant over several years.
- There are no anticipated changes in FYE or WYE levels.

Budget Process



NASA Programs Benefiting from and Co-funding the NDE Program

- **RVDS - Robust Vehicle Design and Sustainment**
- **VHMS - Vehicle Health Management Systems**
- **SFW - Subsonic Fixed Wing**
- **SRW - Subsonic Rotary Wing**
- **HYTHIRM - HYpersonic THermodynamic InfraRed Measurements**
- **ACT - Advanced Composite Technology**
- **Heavy Lift Launch**
- **James Webb Space Telescope (JWST)**
- **Global Precipitation Measurement (GPM)**
- **Magnetospheric MultiScale (MMS)**
- **Satellite Servicing**
- **Landsat Data Continuity Mission (LDCM)**
- **Express Pallet**
- **ISS – Engineering**
- **JWST (James Webb Space Telescope) - Weldments**
- **CEV/Orion – Engineering**
- **NASA Aircraft, Facilities- Aircraft, Pressure Systems, Motion-Based Simulator Welds**
- **ISS & Orion - Critical Profilometers, welds**
- **Acousto Optic Measurement with Fiber Bragg Gratings - ISS**
- **Multi-Axial FBG System for Real-Time NDE Inspection – ISS**
- **Aircraft Aging and Durability (AAD) - NDE of Composite Weaves**
- **Integrated Vehicle Health Monitoring (IVHM) - *in situ* Engine NDE**
- **Advanced Stirling Converter – X-ray CT**
- **Complex Aerospace Structures - Flexible Path Vehicle TPS**
- **Aviation Safety**
- **Fundamental Aero**
- **NESC(COPV NDE, shuttle external tank, ORION ablator shield backing, flow control poppit NDE)**
- **NASA Standards - POD**
- **NESC - flight certification**
- **Institutional/facilities (Pads, VAB,OPF, Cranes, Transporters, etc)**
- **Institutional/cryotank**
- **NDE of Flight Hardware (satellite systems)**
- **NDE- Engineering**

Budget Strategy

- **FY13 proposals reviewed and ranked by NNWG**

		Proposals for Consideration: FY13																
			Rankings															FY13 Cost
Proposal No	Center-*	Filename	ARC	DFRC	GRC	GSFC	JPL	JSC	KSC	LaRC	MSFC	SSC	WSTF	Totals	Avg Score	Std Dev	Rank	K
	WSTF	Repair of a Portable Industrial X-ray Radiographic System																
2	JSC-1	Development of Eddy Current C-Scanning with Wireless Encoder		1	6	1	6	X	1	1	2		4	22	2.8	2.3	8	$107
6	WSTF-1	Vessel (COPV) Laser Profilometer to a Universal NDE Scanner, Meeting Manufacturing and Analytical Needs (i.e., "Smart COPVs")		2	3	3	4	4	2	2	4.5		X	24.5	3.1	1.0	9	$110
1	GSFC-1	Computed Tomography		5	4	X	1	5	5	4.5	2.5		2	29	3.6	1.6	10	$61
4	GRC	Heater Head Detectability Study		3	X	2	2	3	7	4.5	2.5		5	29	3.6	1.7	10	$69
7	DFRC	DFRC NDI Lab Support R2		X	1	6	8	2	4	7	7		1	36	4.5	2.9	12	$22
3	LaRC-1	Assessment of EC for Smart COPV NDE		7	5	4	5	7	3	X	4.5		3	38.5	4.8	1.6	13	$236
	MSFC-1	Augmentation Proposal For GPGPU Assisted Thermograpic Compostiting Project		6	2	5	7	1	6	6	X		6	39	4.9	2.2	14	$144
5	KSC-1	NDE and Sturctural Health Monitoring of Composite Repairs		4	7	7	3	6	X	3	5		7	42	5.3	1.8	15	$92

- **Insufficient resources to initiate any major NDE tasks in FY13**

Explanation of Program Changes

Program changes since the release of President's FY2013 budget request (February 13, 2012).

- The NDE Program is consolidating recent advances in nondestructive evaluation of the integrity of composite overwrapped pressure vessels(COPV) to produce a Smart COPV that will continuously indicate the remaining life and provided adequate advanced notification of impending catastrophic failure.

- The NDE Program has accelerated work on the detection of counterfeit electronic parts by slowing down work on validation of probability of detection methods used for fracture critical systems and by eliminating new start NDE activities for FY13.

Budget Strategy (continued)

- **The existing probability of detection (POD) physical Standards, document Standards, and POD methodologies are dated, with some being over 25 years old. Risk is introduced when physical Standards and documents no longer have the required pedigree or credibility. In an effort to remove this risk, the NDE Program supports the development of new physical POD Standards, updated document Standards and new POD methodologies.**

- **Composites are used throughout NASA systems. Composites remain to be an inspection challenge. The wide variety (over 50) of composite systems has increased this challenge. When inspection methods for a particular composite system are developed, it is often determined that the same inspection methods do not transfer well to other composite systems. This lack of transferability is made more apparent where there are an unlimited number of composite material and structural configurations. With this in mind, the NDE Program is supporting focused efforts addressing the primary mission critical composite inspection needs and to develop inspection methods with cross-cutting applications. The NDE Program is addressing hybrid structural composite systems for satellites and crew systems, hybrid composite thermal protection systems, and composite over-wrapped pressure vessels (COPVs).**

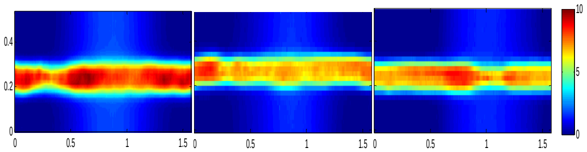
    - **There is little inspection experience with detecting manufacturing flaws of these hybrid composite thermal protection systems *(Phenolic Impregnated Carbon Ablator (PICA) and Avcoat)*. The NDE Program is supporting the development and assessment of NDE technologies for characterization of structural mismatch between support structures, disbonds, and voids.**

Budget Strategy (continued)

- **Composite overwrapped pressure vessels provide a unique NDE challenge. The NDE activities are focused on evaluating the integrity of the vessel and the vessels propensity to prematurely fail during use. The two aspects to be addressed are the manufacturing quality and the integrity of the vessels during use. Previously, there were no accepted Standard practices for inspecting COPVs. The NDE Program is addressing this supporting the development of six voluntary consensus Standards for flat composite panels with industry and ASTM. These Standard practices have been completed and accepted, however, they are not specific to COPVs, but rather they are for flat plates. The NDE Program is continuing this leadership to include Standard practices for COPV composite overwraps and COPV liners. ASTM has accepted registration for two Standards (Composite Overwraps and Thin-walled Liners) and industry – government teams have been assembled. While these Standards are being developed, the NASA NDE Program is supporting the development and demonstration of inspection technologies for carbon COPV manufacturing process control, COPV acceptance, and in-situ health monitoring of COPVs. NDE Program developed tools are in current use at multiple sites. In FY12, the NDE Program initiated the "Smart Composite Vessel" project. The goal of this project is to develop a COPV with the integral sensors necessary to provide real-time evaluation of COPV integrity and provide life-time remaining.**

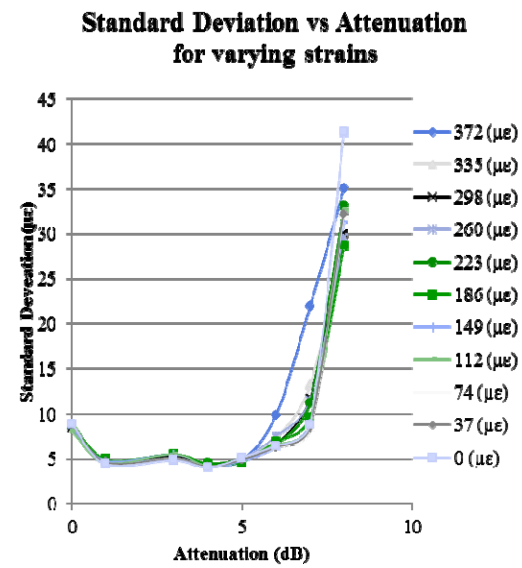
- **The health monitoring of stiff structures has been under development by the NDE Program. Demonstration of a self-reconfigurable impact detection (and location) structural skin has been successful. The demonstration system is a concept demonstrator (CD) test bed for evaluating a wide variety of health monitoring sensing technologies. Both impact location and damage level are now available, and utilize existing acoustic emission technology. The sensing skin is auto-reconfigurable, so that when damage is sufficient great to damage sensing elements, alternate communication paths are established to maintain real-time knowledge of the structural integrity and the extent of damage. In FY12, this work is being extended by the NDE Program to include a thermal protections system (TPS).**

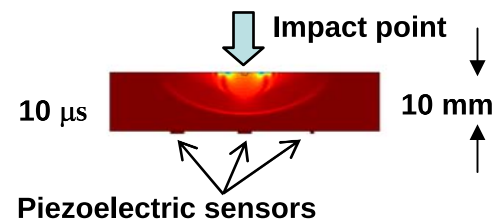
Nominal Porosity Lack of Fusion

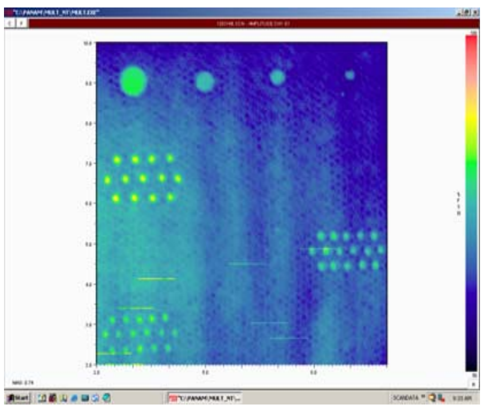


Probability of Detection of Flaws Internal to COPV Liner 50% Less that Standards

Thermal Protection System Real-time Health Monitoring

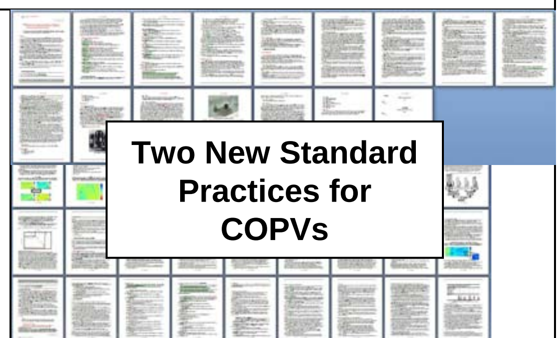


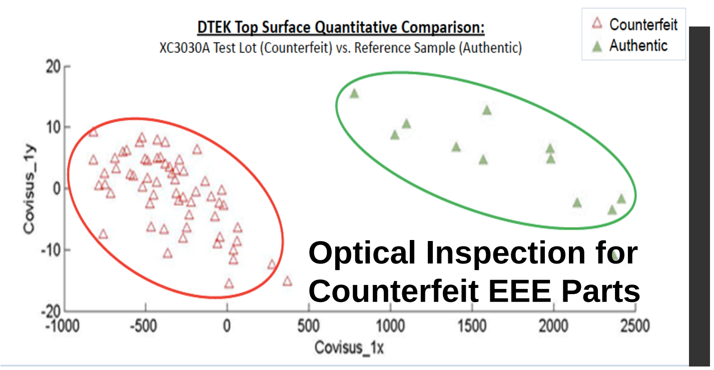




Hybrid Composite - Honeycomb Bond Integrity- GPM (Global Precipitation Measurement and MMS (Magnetospheric Multiscale).

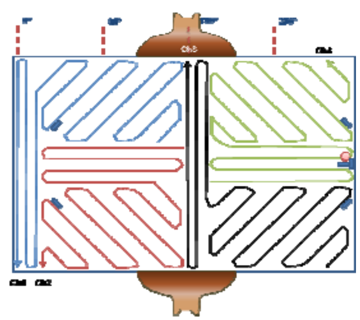
Ultrasonic pulse echo C-scan





Optical Inspection for Counterfeit EEE Parts

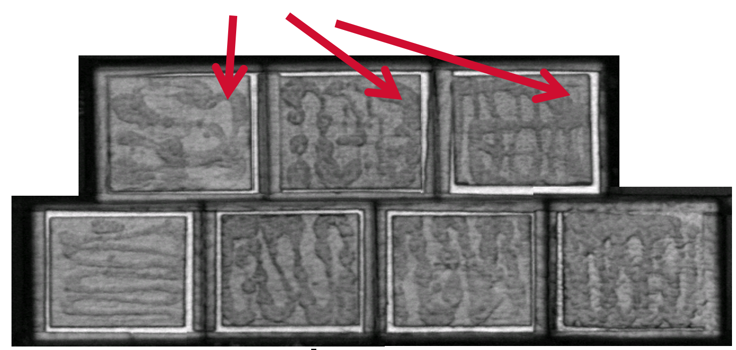
Smart Composite Pressure Vessel



Multiaxial Fiber Sensors

Inspection Methods for Orion TPS Integrity

Bond / Adhesive Areas

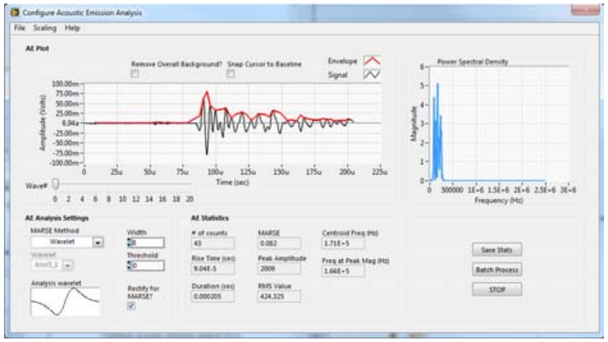


Terahertz Images

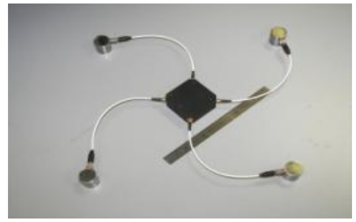
COPVs in Wide Use

Smart Composite Overwrapped Pressure Vessel

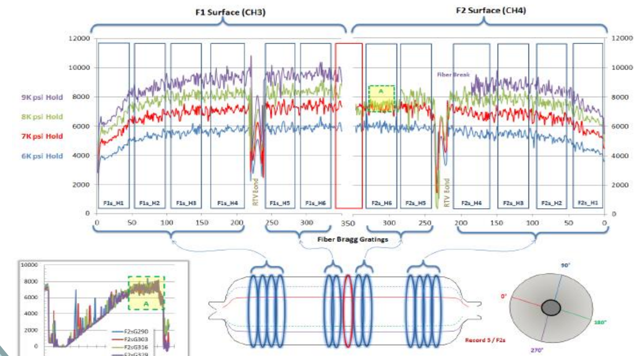
GRC Acoustic Emission Analysis Applet



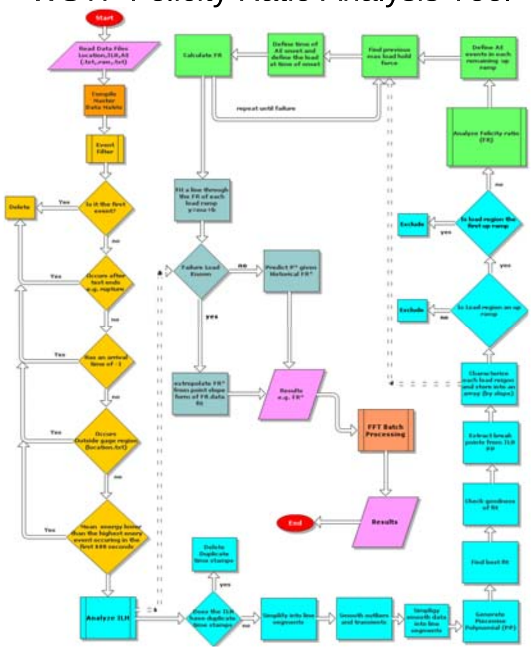
LaRC Distributive Impact Detection System Acoustic Emission



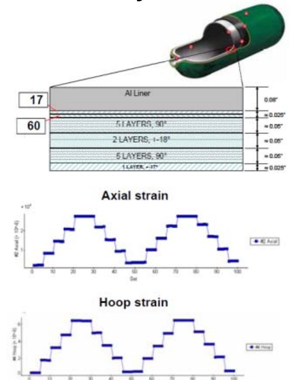
DFRC Multiaxial Fiber Bragg Gratings



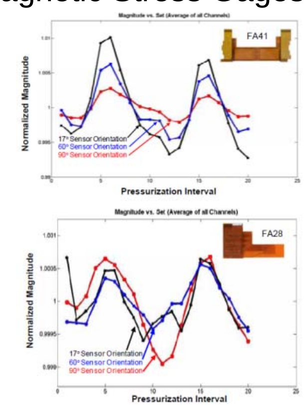
WSTF Felicity Ratio Analysis Tool



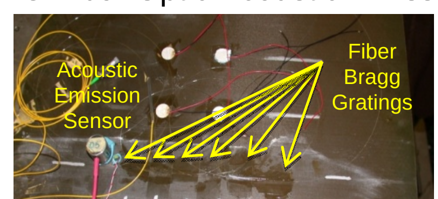
KSC Eddy Current

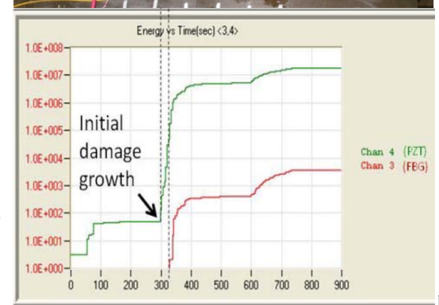


Magnetic Stress Gages

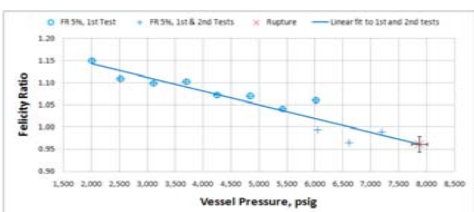


MSFC Fiber Optic Acoustic Emission

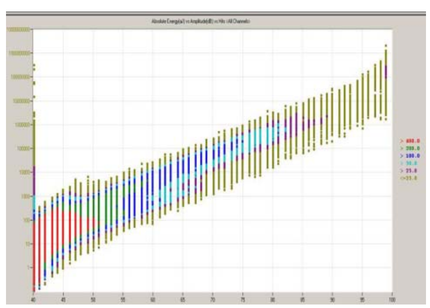




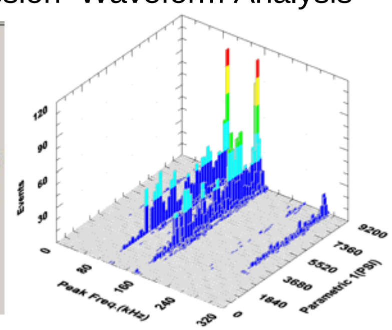
WSTF Composite Overwrapped Pressure Vessel Burst Prediction



Conventional Acoustic Emission



Waveform Analysis



Major/Key Achievements in FY2012

- Designed orbital weld eddy current probe. Fabrication underway.
- Designed carbon nanotube sensor package for impact detection sensors for inflatable structures.
- Identified NDE methods for evaluation of PICA thermal protection systems. TeraHertz imaging shows promise.
- Identified optical quantitative machine that can detect counterfeit EEE hardware.
- Completed process development for honeycomb partial cell wall bonding defects.
- Established that penetrant crack detection length for the interior tube wall surfaces (0.111 inches) was significantly larger than the estimated for the exterior surfaces (0.062 inches).
- Demonstrated vehicle health monitoring technology for both thermal (loss/degradation of TPS) and acoustic sources (MMOD) using fiber Bragg grating network on a small-scale composite test panel.
- Identified light weight erbium-doped fiber ring laser (EDFRL) has adequate properties for above health monitoring system.
- 1600 multiaxial fiber Bragg grating sensors installed on Smart COPV.
- Completed two COPV Standards (applicable to NASA COPVs) with balloting scheduled for ASTM E07.
- Demonstrated accelerated (25% increase in speed) graphics processing method for image processing/analyzing large area mosaic NDE data (thermal imaging data).
- Updated NASA's binomial Probability of Detection (POD) method to assure credible results. Materials Evaluation December 2011, NASA/TP-2011-217176

Issue Paper(s)

The Mission Support FY 2013 Budget Program and Resources Guidance (PRG) requires OSMA to: "Address plans for Micrometeoroid Orbital Debris (MMOD) and counterfeit parts programs. Address plans to meet the direction in the 2010 NASA Authorization Act."

NDE Program Supports

- **MMOD**
  - **MMOD Impact Detection Sensors for Inflatable Structures**
  - **Monitoring of Thermal Prot Sys Using Robust Self-Organizing Optical Fiber Sensing Networks**
  - **Tunable Laser Development for In-flight OFDR Structural Health Monitoring Systems**
  - **NDE of Ablative Heat Shield Materials and Structures for NASA Missions**
  - **X-ray & Terahertz studies (including 3D Computed Tomography) for Complex Aerospace Structures**

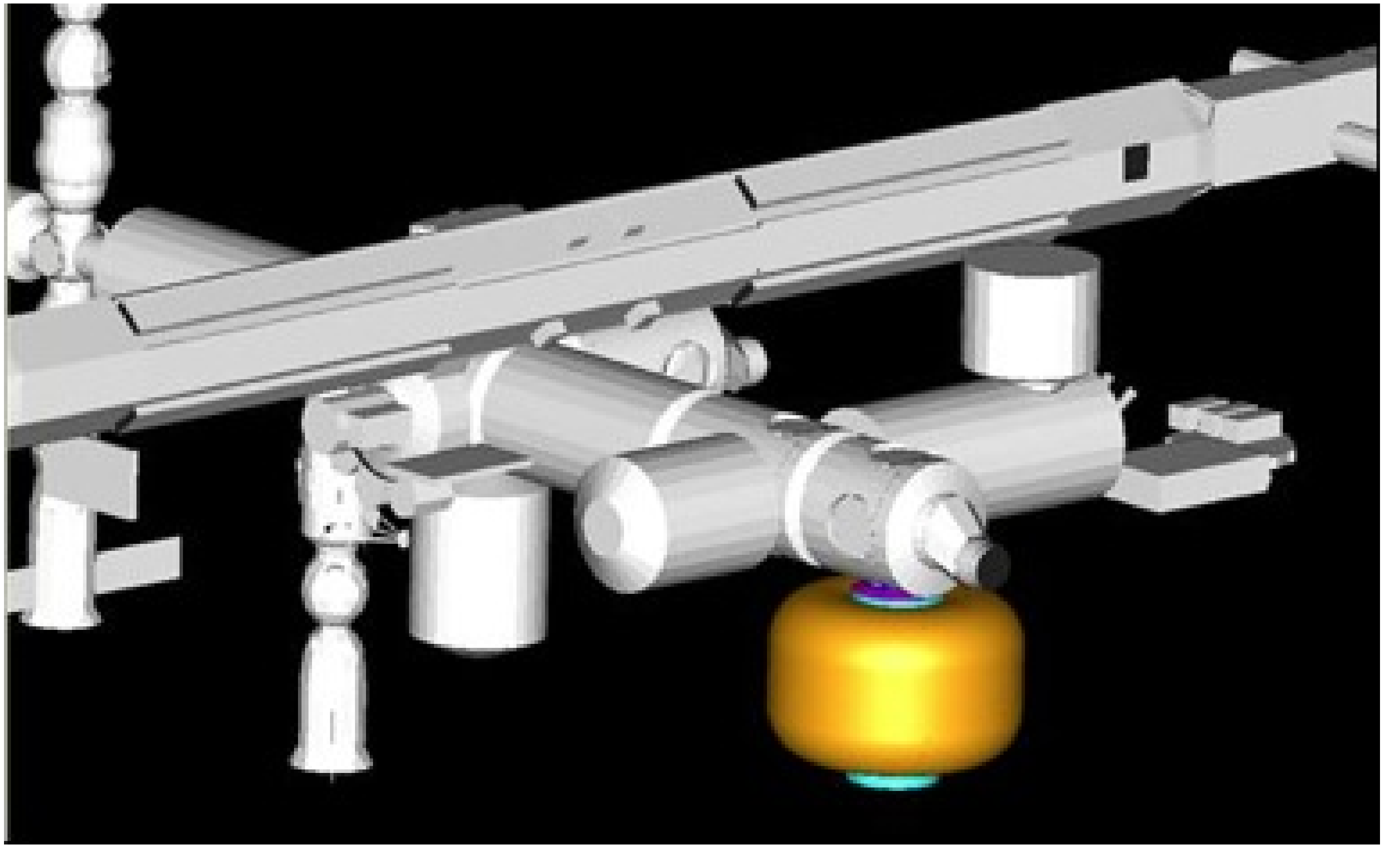
- **Counterfeit EEE Parts**
  - **NDE Techniques for Suspect Counterfeit EEE Parts**

Summary

Backup

MMOD Impact Detection Sensors for Inflatable Structures

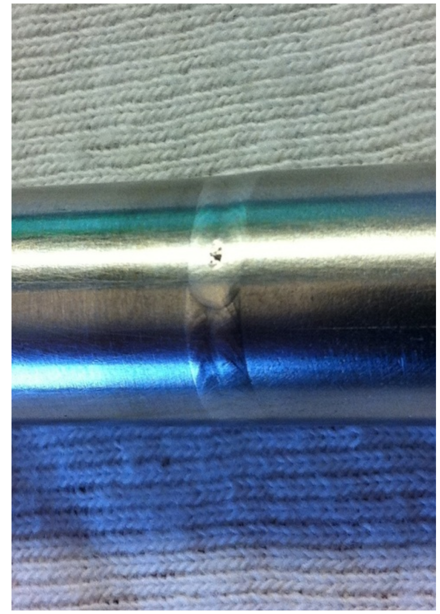
BEAM - Bigelow Expandable Activity Module for International Space Station (ISS)



Development of In-Situ NDE Techniques for Inspection of Welded Tubing Used in Spacecraft

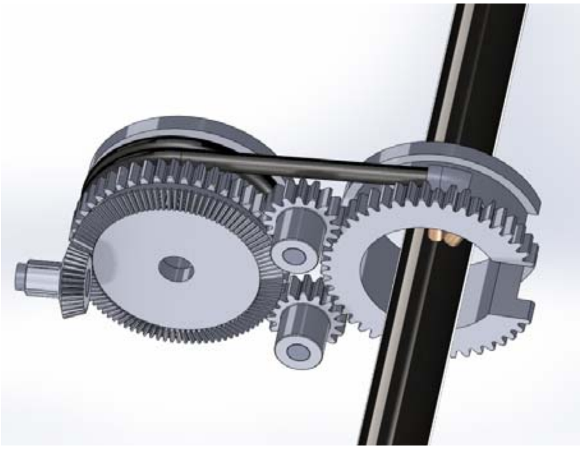
Lack of Fusion

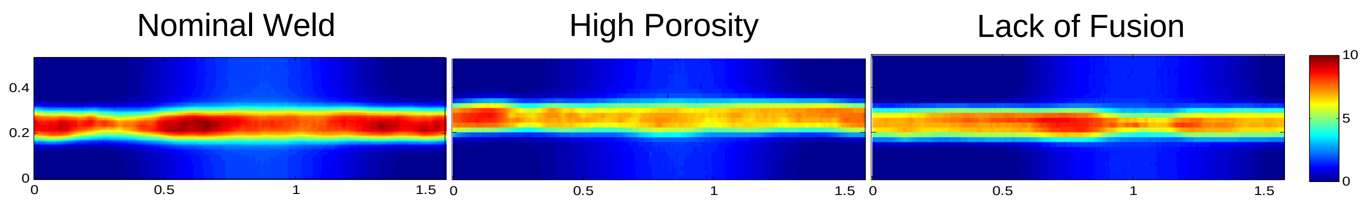
Acceptable

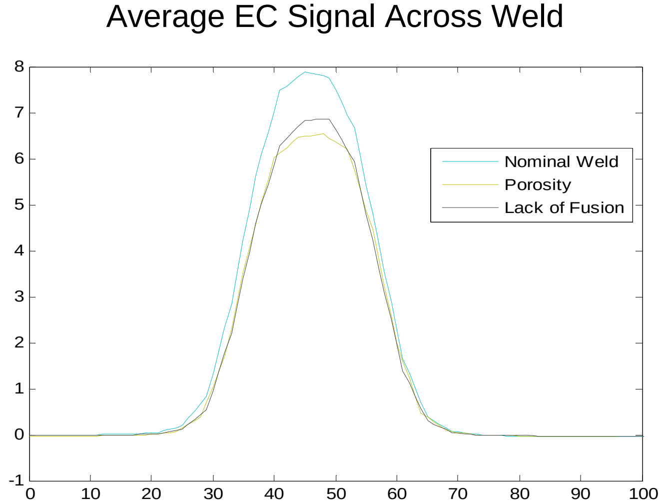


Porosity

Orbital EC Inspection Tool



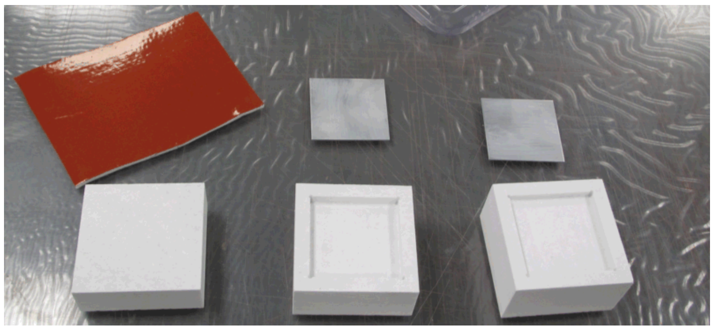




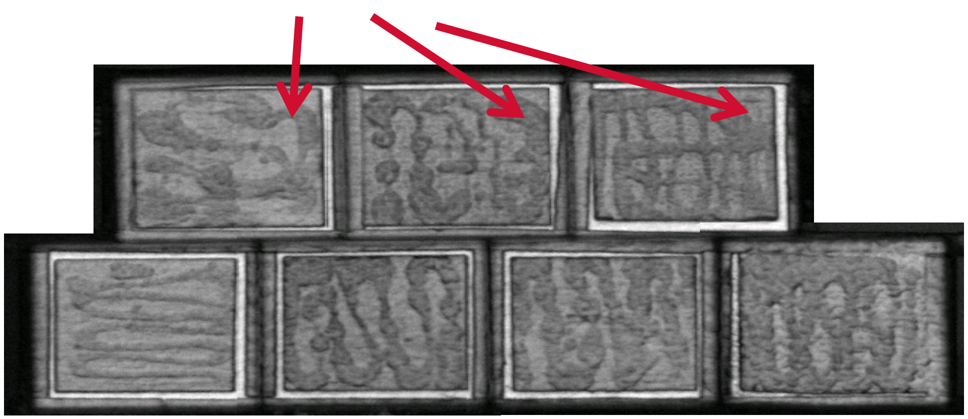
Initial Eddy Current Inspection of Tubes

NDE of Ablative Heat Shield Materials & Structures for NASA Systems

New Disbond Block

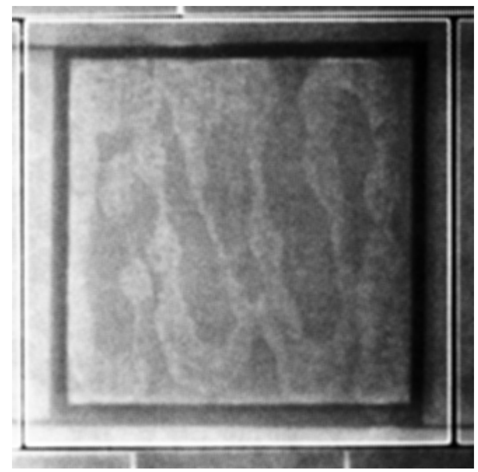


Bond / Adhesive Areas

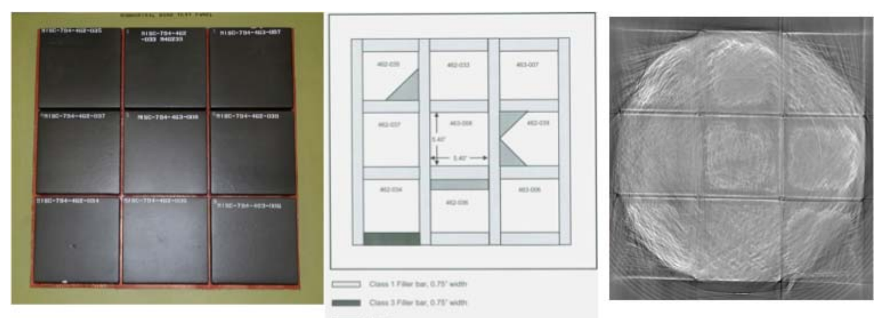


Terahertz Images

BSX Results with high collimation
and image processing produced better results



CT Scan Results – not detected



Step 2: Load Component Samples

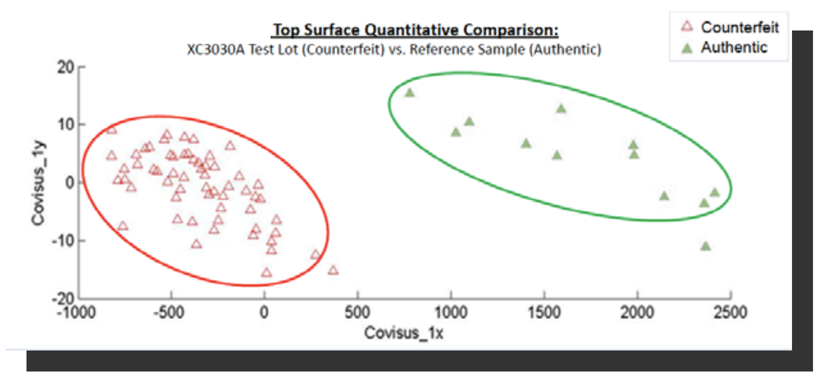
Step 3: Scan Top Surfaces

Step 4: Flip Components

Step 5: Scan Bottom Surfaces

Summary results have three potential outcomes:

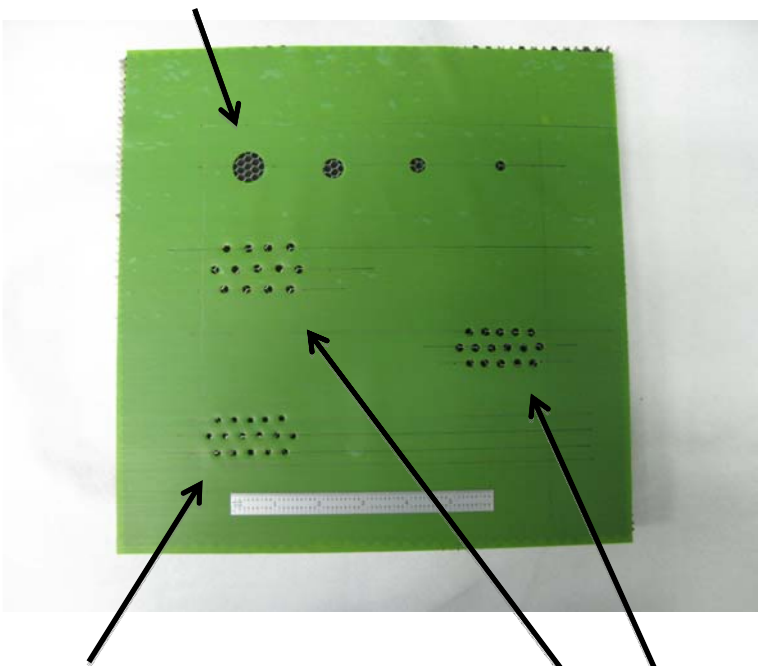
- ✓ **Pass**
- ✗ **Fail**
- N/A **Not Applicable**



NDE of Composite Honeycomb Sandwich Defects

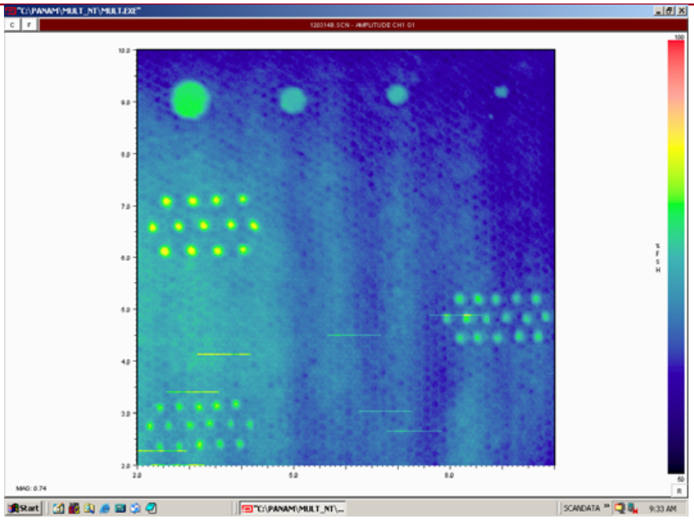
Process development panel for honeycomb cell size panel with partial cell wall bonding.

Defects

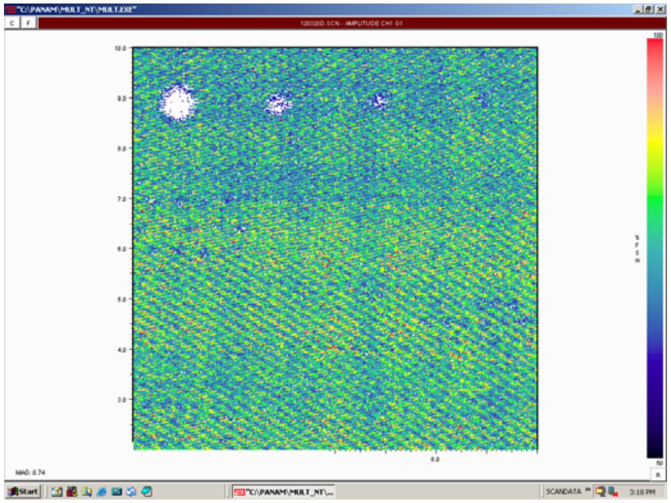


Bottom left cluster are cut outs were deemed too small to place back onto core.

Two clusters defects.



Ultrasonic pulse echo C-scan at 10 MHz. Data acquisition gate set on facesheet to core ring down.



Ultrasonic through transmission squirter C-scan at 1 MHz.

Probability of Detection (POD) Demonstration Transferability: Phase II

The larger cylinder has a 16 inch diameter and 32 inch height. Panels are inspected centered in the cylinder.

The smaller cylinder has a 12 inch diameter and a 24 inch height. Panels are inspected either fully populating the cylinder, or populating one end with inspection from the opposite end.

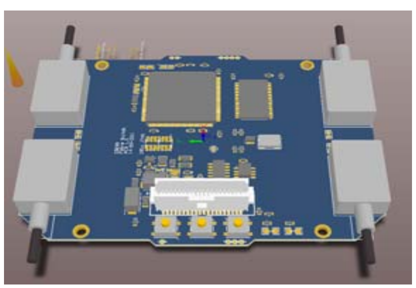
Format	Number of Cracks	Number of Hits	Number of Misses	Estimated a90/95 (inches)
Flat Panels	81	80	1	0.026
Large Cylinder	81	73	8	0.078
Small Cylinder: Full	81	78	3	0.048
Small Cylinder: Half	81	76	5	0.055

Demonstration test results for Inspector 3.

Monitoring of Thermal Protection Systems using Robust Optical Fiber Networks

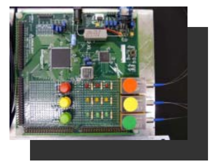
NASA / CSIRO
Concept Demonstrator

Large-scale testing at DFRC

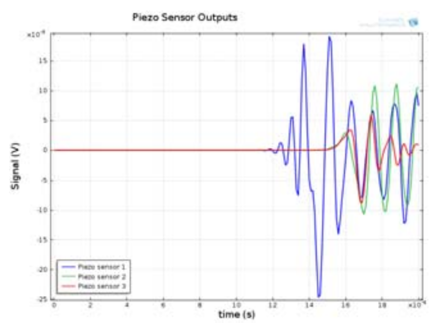


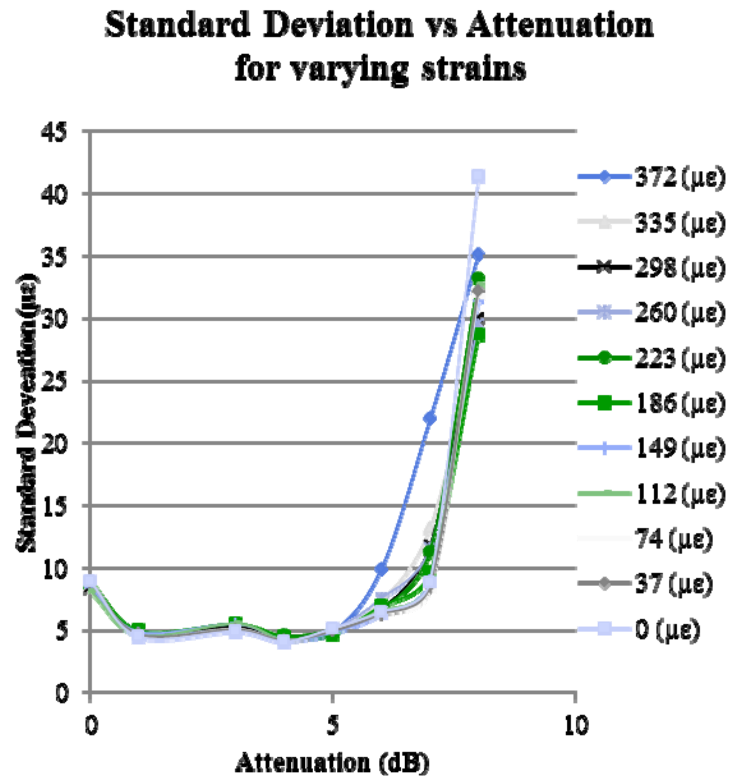
Control electronics design for distributed intelligent control of the switched network

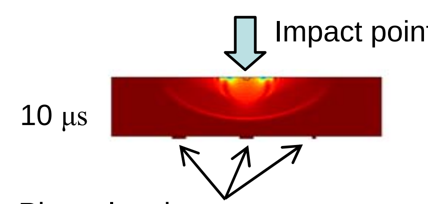
- COMSOL modelling of ceramic foam block
- Short pulse impact at upper centre
- Three piezoelectric sensors bonded to lower surface of block
- Signals from:
    - centre sensor (blue);
    - right (small) sensor (red)
    - left sensor (green).



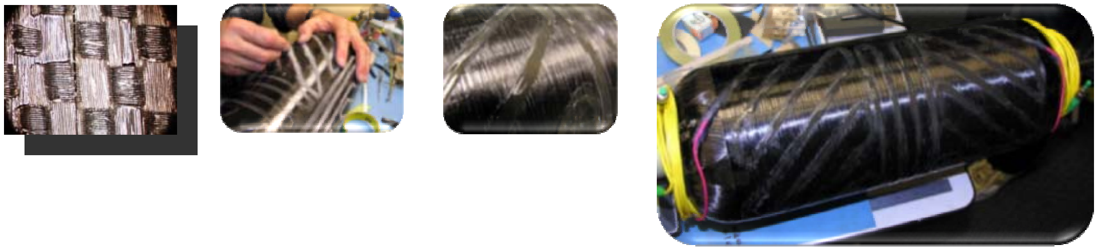
Controller for 3-way optical switches



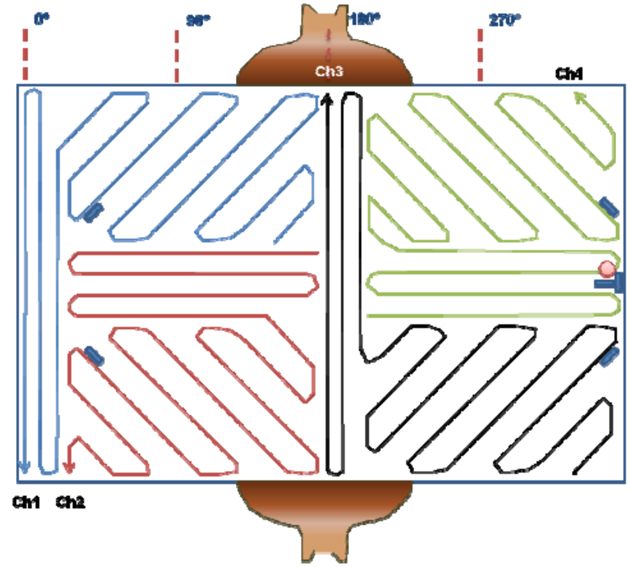




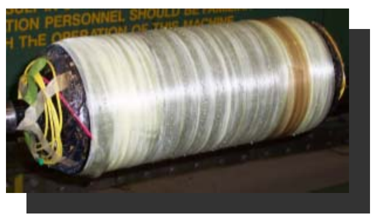
Multi-Axial FBG System for Real-Time NDE Inspection



FBG Installation Techniques developed



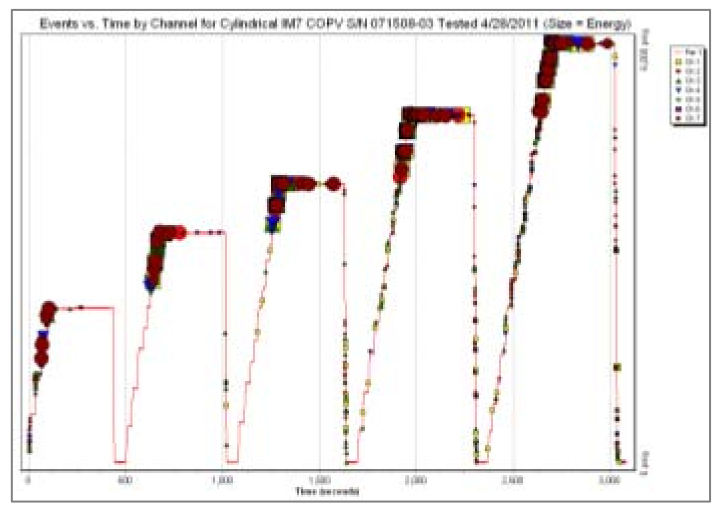
Surface FBGs



Overwrapped bottles

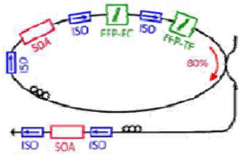
Surface / Embedded FBG Bottle tests

Group Photo at Test Cell 860 (White Sands Test Facility)

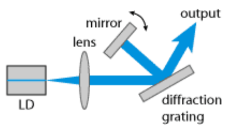


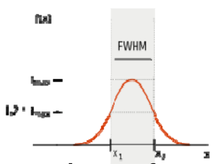
Acoustic Emission Energy Plot

Tunable Laser Development for In-flight OFDR Structural Health Monitoring Systems

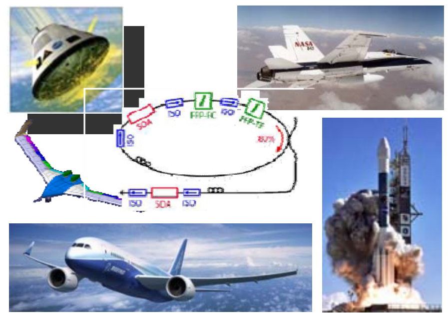


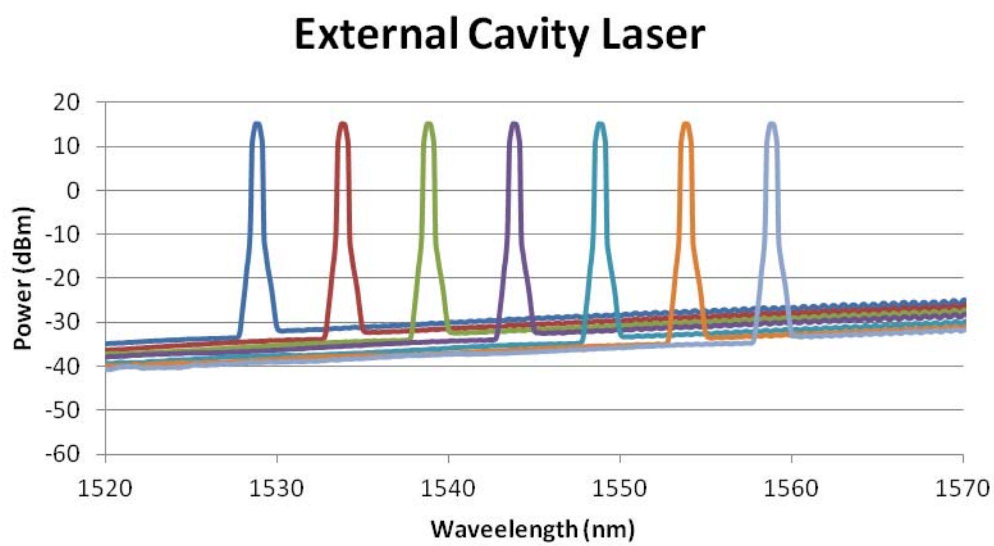
External Cavity Laser tuning mechanism



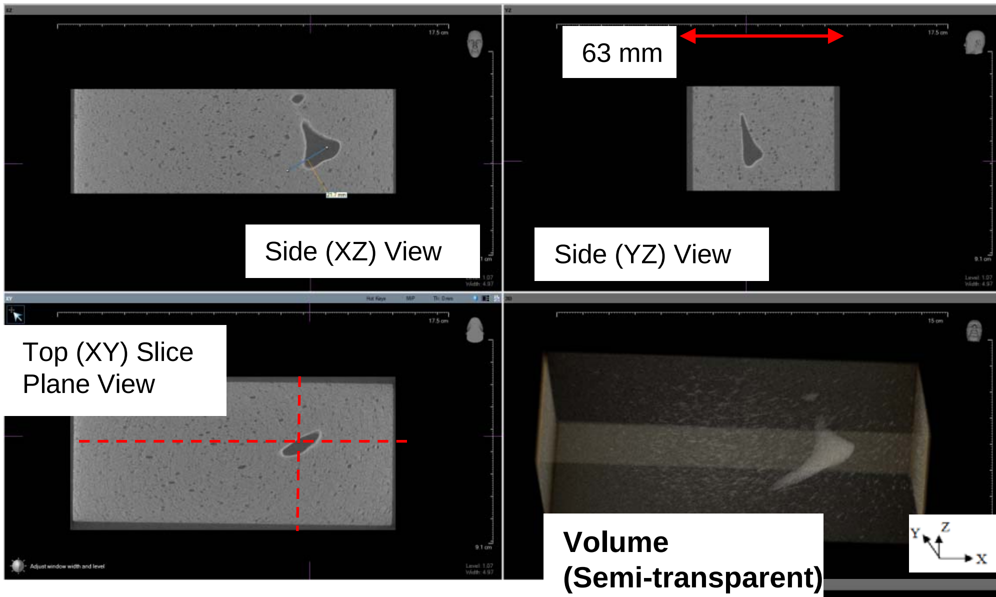


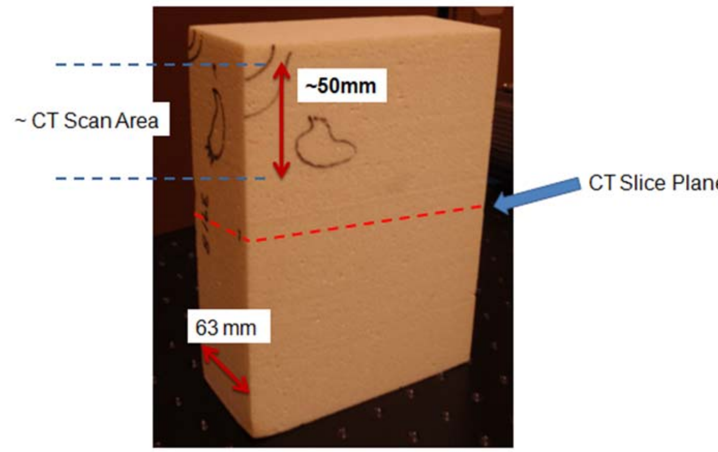
Laser tuning performance



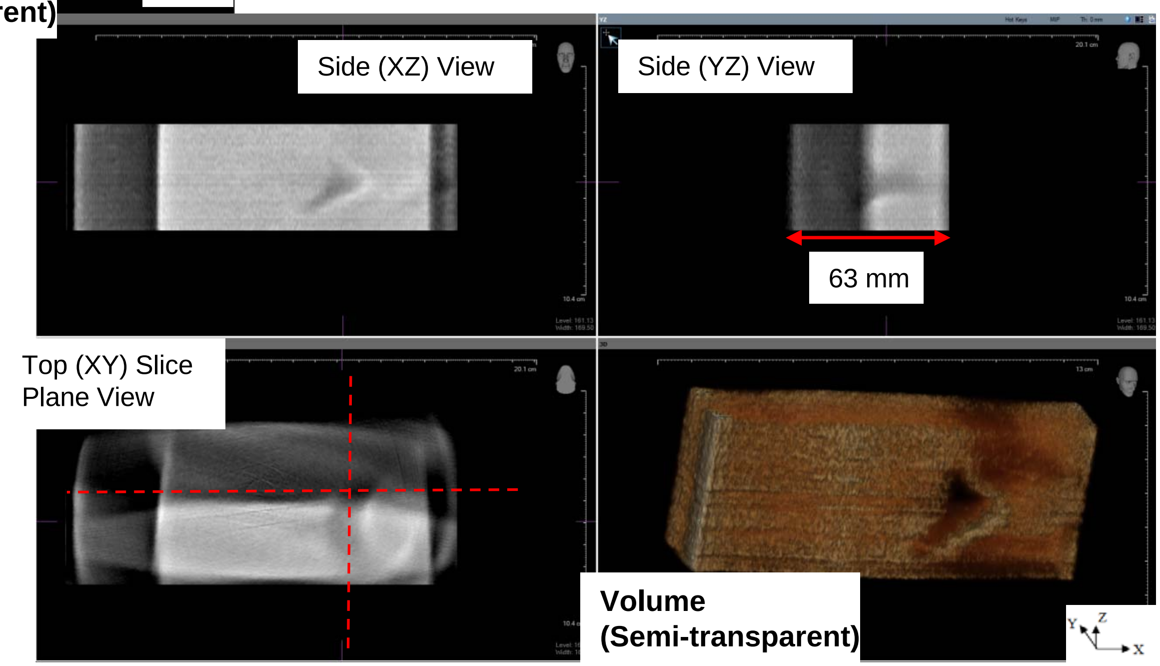


Foam Block with Embedded Void
Analyzed with Terahertz and X-ray Computed Tomography



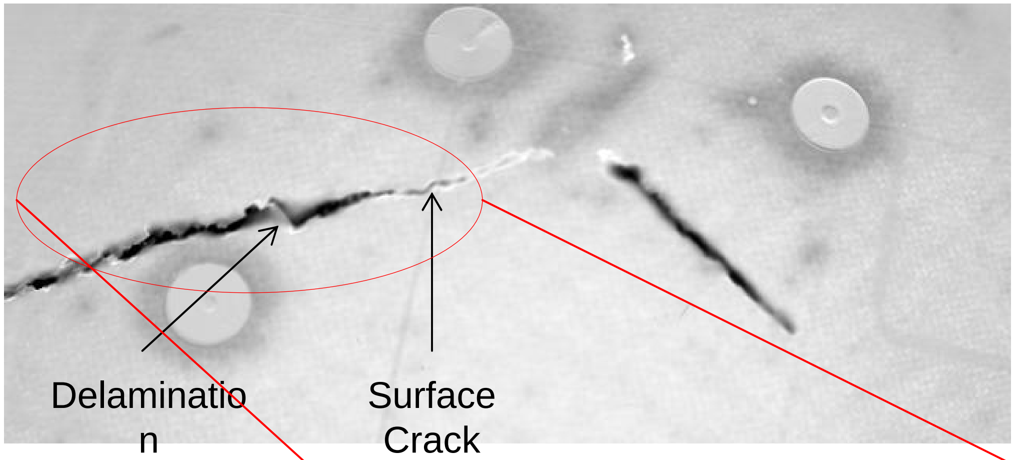


• **X-ray computed tomography**

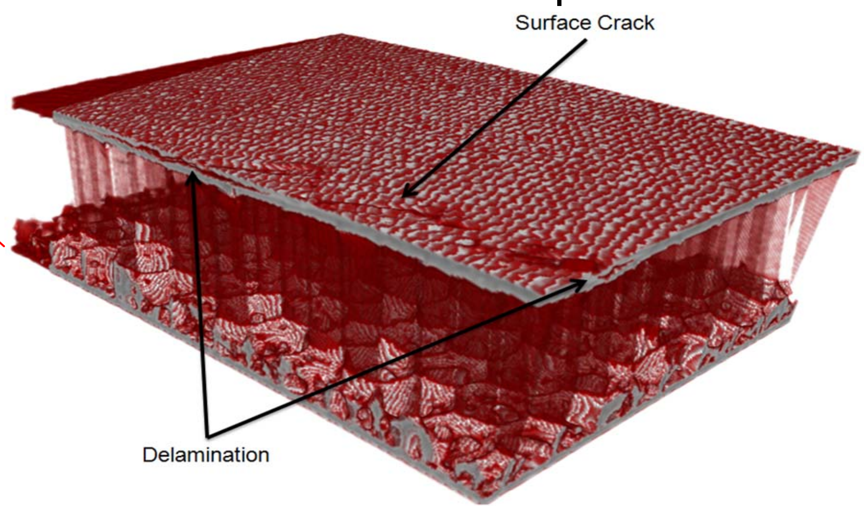


• **terahertz computed tomography**

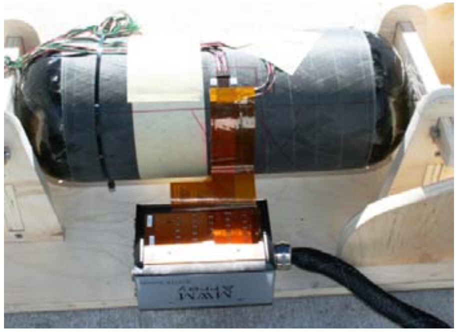
NDE of Composite Honeycomb Face Sheet Bonding

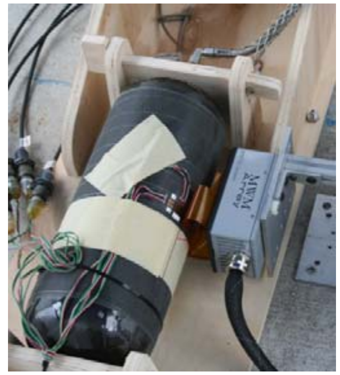


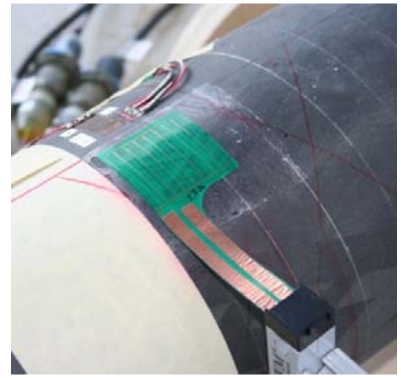
Model Based PCA processed flash thermography image of impact damage in honeycomb composite



High resolution Xray CT image confirming the thermography results

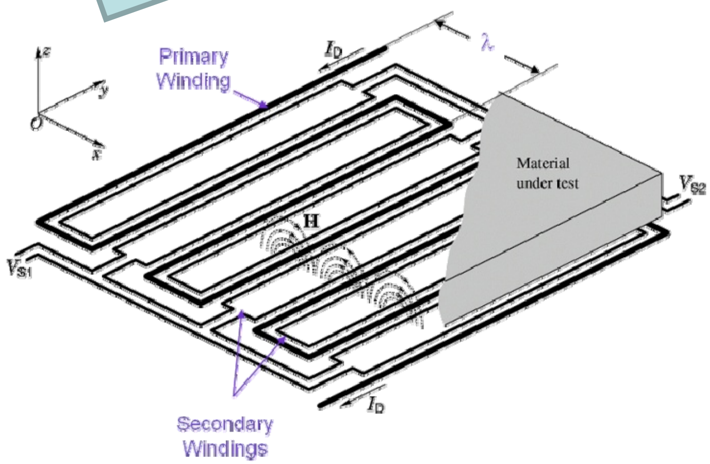




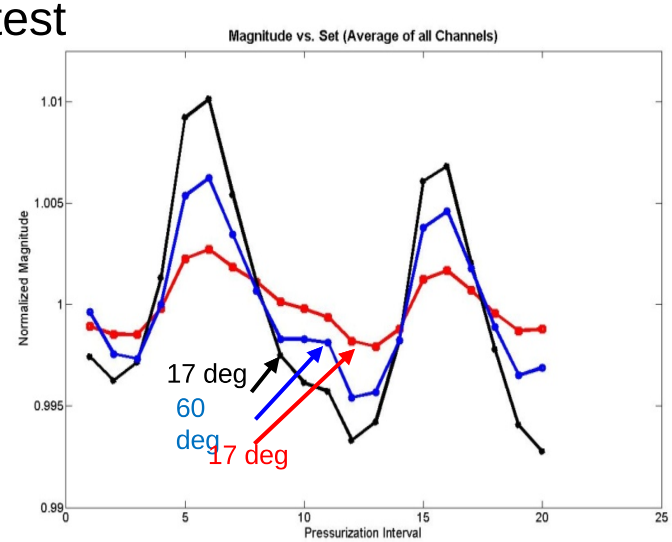


Health Monitoring of Composite Overwrapped Pressure Vessels

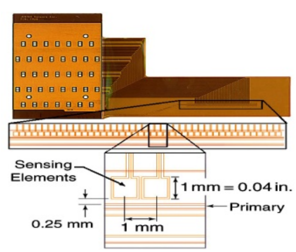
KSC Proof of concept Hydrostat test

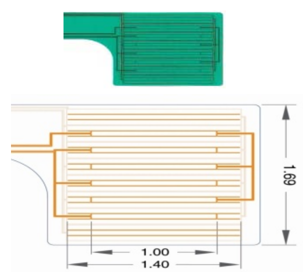


Basic Meandering Winding Magnetometer (MWM) design



Example results for one of the tested sensors



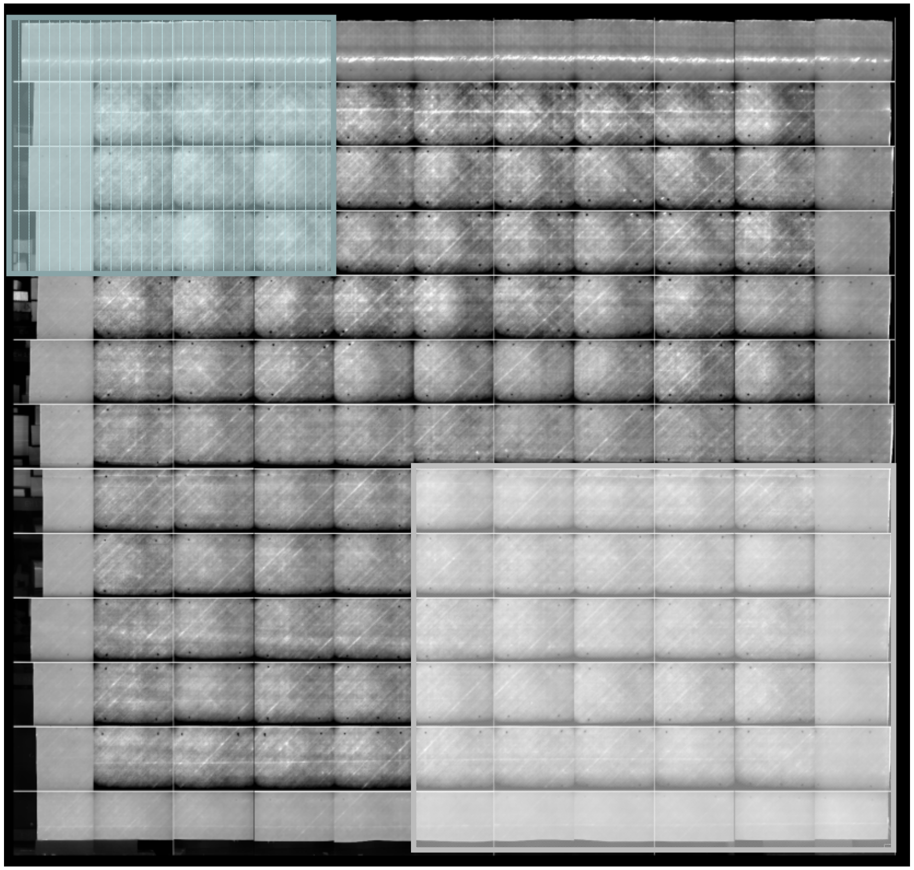


3 types of sensors used – each tested at 3 different angles

Graphics Processing Unit Thermographic Compositing

In-development software enables twice the number of data files to be analyzed simultaneously when compared to the current off-the-shelf software product.

Current system



GPU-accelerated system

Composite Panel (143 files)

Budget Topics:

Voluntary Consensus Organization Standards for Nondestructive Evaluation of Composite Overwrapped Pressure Vessels

Schedule/Plan/ Milestones:

Description	Milestone Date
Select NASA Technical Points of Contact for various NDE Sections	10/2011✓
a) Status Committee E07 and NASA on balloting progress b) Initiate 5-year re-approval cycle for E2580-07, E2581-07 and E2582-07	1/2012✓
Submit WK29068 for first round of subcommittee balloting	2/2012✓
Submit WK29034 for first round of subcommittee balloting	5/2012
a) Status Committee E07 on WK29034/WK29068 balloting progress b) Submit E2580-07, E2581-07 and E2582-07 for subcommittee balloting	6/2012
a) Submit WK29034/WK29068 for main committee balloting b) Re-balloting of E2580-07, E2581-07 and E2582-07 as needed	10/2012
a) Status Committee E07 and NASA NDE Working Group on balloting progress b) Status NNWG on FY12/current accomplishments c) Establish feasibility for a Guide for NDE of COPVs d) Propose NNWG FY14-on effort (if needed)	1/2013
Respond to Spring balloting call as needed	3/2012
Status Committee E07 and technical writing teams on balloting progress, resolve any last negatives	6/2013
a) Secure formal adoption for WK29034 and WK29068 b) Obtain re-approval of E2580-12, E2581-12 and E2582-12	8/2013
Disband the E07.10 Task Group on NDE of Aerospace Composites, or define carry-on effort for FY14 onwards	9/2013

Significant Accomplishments:

Since 2005, six standards have been issued under the jurisdiction of American Society of Testing and Materials Committee E07 on NDE:

1)*Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications*, E 2580 (2007) (5-year revision WK36078 registered 1/19/12)
2)*Practice for Shearography of Polymer Matrix Composites, Sandwich Core Materials and Filament-Wound Pressure Vessels in Aerospace Applications*, E 2581 (2007) (5-year revision to be registered)
3)*Practice for Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications*, E 2582 (2007).(5-year revision to be registered)
4)*Practice for Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications*, E 2662 (2009)
5)*Practice for Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications*, E 2661/2661M (2010)
6)*Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications*, E 2533 (2009)

Two new Work Items were formally registered with E07 in 2011:

1)*New Practices for Examination of the Composite Overwrap in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing*, WK 29034 (balloting initiated 2/15/12)
2)*New Practices for Examination of the Thin-Walled Metallic Liners in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing*, WK 29068 (balloting to be initiated by 5/15/12)

The above Work Items consist of 13 NDE sections, each with a separate writing team (focus is to promulgate newer, more sensitive techniques)

Over 50 pages of technical detail have been written to date

Issues /Concerns:

WK 29068: NASA documents (e.g., NASA-STD-5009) levy 95/90 Probability of Detection requirements that cannot be met for current thin-walled liner designs

- Probability of Detection studies for 'Standard NDE' are for Shuttle era materials and techniques
- Probability of Detection studies for 'Special NDE' for smaller flaws do not exist or do not meet 90/95 requirements
- Either lower Probability of Detection or greater risk must be accepted, or Safety Factors must be increased (thickness/weight), or newer, more sensitive NDE techniques must be developed and supporting studies conducted

WK 29034: 95/90 Probability of Detection requirements have little relevance to composites because of the myriad of flaw types and the lack of 'effect of defects'

- Accept-reject based on engineering experience, not a specific flaw size
- Viable NDE techniques must be able to detect out-of-family behavior or flaws below the visible detection threshold

Accomplishments Since 2005 and Current Plan

2005

Designation: E 2533 – 09

Standard Guide for
Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications[1]

Designation: E 2580 – 07

Standard Practice for
Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E 2582 – 07

Standard Practice for
Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications[1]

Designation: E 2581 – 07

Standard Practice for
Shearography of Polymer Matrix Composites, Sandwich Core Materials and Filament-Wound Pressure Vessels in Aerospace Applications[1]

Designation: E 2662 – 09

Standard Practice for
Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications[1]

Designation: E2661/E2661M – 10

Standard Practice for
Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications[1]

2010

NDE of Flat Panel Composite Standard Practices and Guide

2011

2012

5-year re-approval of E2580, E2580 and E2581

ASTM WK29034

(What is a Work Item? / How to Input to a Work Item)

Work Item: ASTM WK29034 - New Practice for Examination of the Composite Overwrap in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing

ASTM WK29068

(What is a Work Item? / How to Input to a Work Item)

Work Item: ASTM WK29068 - New Practice for Examination of the Metallic Thin-Walled Liners in Filament Wound Pressure Vessels Used in Aerospace Applications by Nondestructive Testing

2013

NDE of Composite Overwrapped Pressure Vessel Standard Practices

Technical Approach – Participants

- NASA
  - GSFC (Parker)
  - JPL (Grimes-Ledesma, Lewis, O'Donnell)
  - JSC (Castner, Forth, Koshti)
  - LaRC (Burke, Madaras, Wincheski)
  - MSFC (Russell, Suits, Walker)
  - WSTF (Saulsberry, Spencer, Waller, Yoder)
- Other Government
  - DOT (Toughiry)
  - NIST (Fekete, McColskey)
  - USAF (Voeller)
- Commercial Aerospace
  - Aerospace Corp. (Johnson, Kenderian, Chang)
  - Boeing (Engel, Gabris)
  - Honeywell (Singh)
  - Lockheed (Nightengale, Rownd)
  - Pratt & Whitney/UTC (James)
  - Space X (Lavoie)
- Standards Development Orgs.
  - AIAA (Lee, notified)
  - ASME (Koehr, notified)
  - ASNT (gave presentation to ASNT in 2010)
- NDE Equipment Manufacturers
  - DigitalWave Corp. (Gorman)
  - Jentek Sensors (Washabaugh)
  - LTI (Newman)
  - Mistras Group, Inc. (Carlos)
  - ThermalWave (Shepard)
  - Westinghouse (Devlin, Drennen, Lareau)
- NDE and Contract Labs
  - A-Scan Laboratories (Collingwood)
  - Israel Assoc. of Engineers & Architects (Muravin)
  - MAST, Inc. (Djordjevic)
  - Metal Finishing Company (Potter)
  - TRI/NTIAC (Matzkanin, Yolken)
- COPV Manufacturers
  - Arde (Sneddon)
  - ATK (Seles)
  - Cobham/Carleton (Cain, Harris)
  - General Dynamics (Heckman)
  - HyperComp (Patterson)
  - Lincoln Composites (Newhouse)
  - Samtech (Zimmerman)
- Academia
  - ERAU (v. K. Hill)
  - Univ. of Denver (Hamstad)

***Practices for NDE of the Overwrap in Composite Overwrapped Pressure Vessels*, WK 29034**

Writing Teams establishing for:

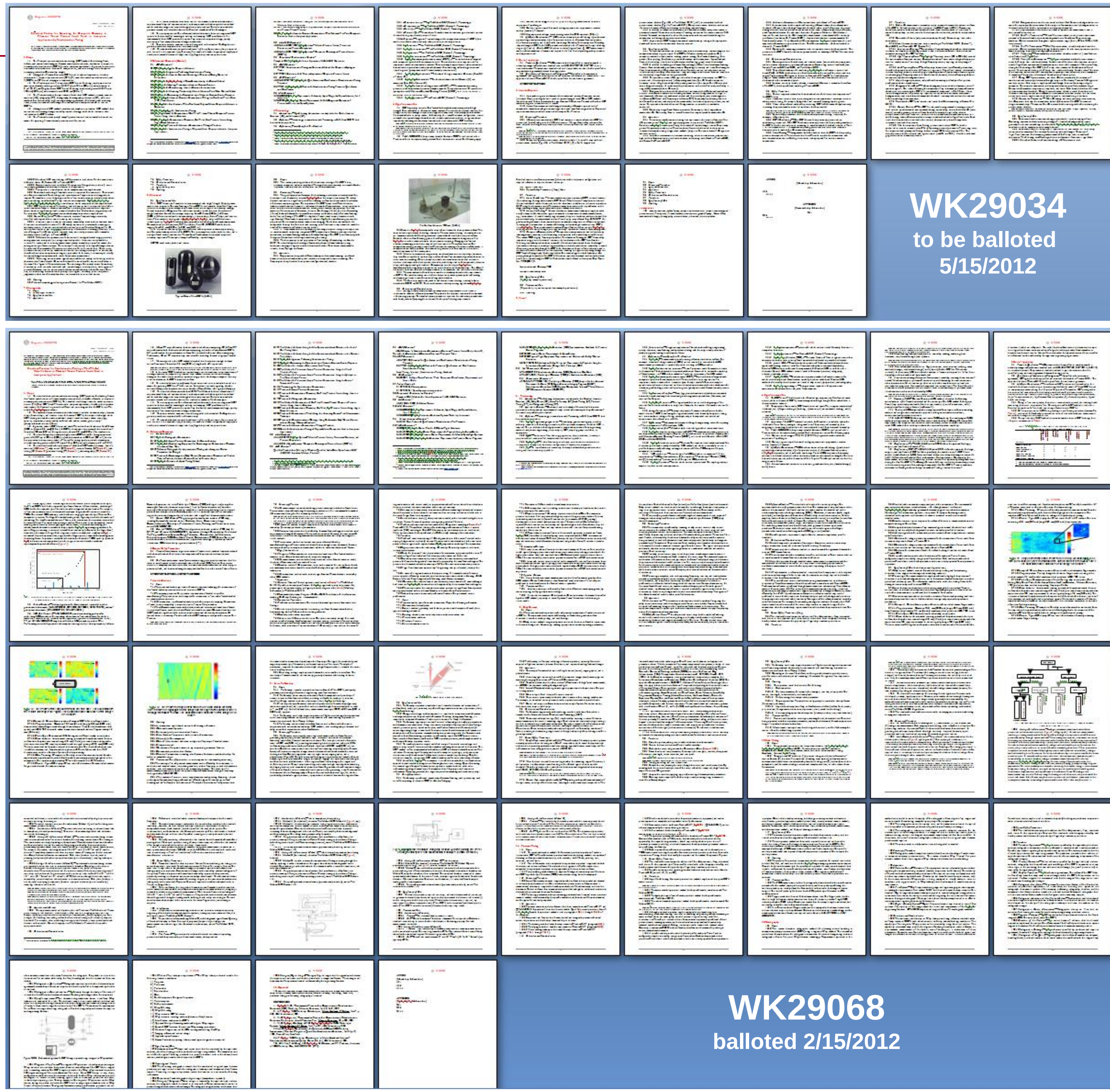
1) Acoustic Emission (Muravin, Newhouse, Toughiry; *Liaison:* Carlos)
2) Eddy Current (Washabaugh; *Liaison:*Washabaugh)
3) Shearography (Newman ; *Liaison:* Clausing)
4) Thermography (Engel, Shepard, Walker; *Liaison:* Clausing)
5) Ultrasonic Testing (James, Djordjevic, Spencer, Burke; *Liaison:* Ruddy)
6) Visual Testing (Yoder; *Liaison:* Clausing)

***Practices for NDE of Thin-Walled Metallic Liners in Composite Overwrapped Pressure Vessels*, WK 29068**

Writing Teams establishing for:

1) Acoustic Emission (Muravin; *Liaison:* Carlos)
2) Eddy Current (Wincheski; *Liaison:* Washabaugh)
3) Profilometry (Saulsberry; *Liaison:* Clausing)
4) Leak Testing (Waller; *Liaison*: Anderson)
5) Penetrant Testing (Castner, Parker, Russell, Suits,Parker; *Liaison:* Collingwood)
6) Radiologic Testing (Engel, Spencer; *Liaison:* Kropas-Hughes)
7) Ultrasonic Testing (James, Djordjevic, Spencer, Potter; *Liaison:* Ruddy)

Draft WK29034 and WK29068 Status



overwrap

liner

Budget Topics:

Smart Composite Overwrapped Pressure Vessel - Integrated Structural Health Monitoring System to Meet Mission Assurance Needs

Significant Accomplishments:

1) **Four promising NDE technologies have been down selected for further development**
   a) Acoustic Emission (microscopic composite damage)
      i. Modal Acoustic Emission
      ii. Distributive Impact Detection System Acoustic Emission ‡
      iii. NDE Wave Imaging Processor-Acoustic Emission Analysis Applet
   b) Multiaxial Fiber Bragg Grating grids (strain) ‡
   c) Fiber Optic Acoustic Emission (damage and strain)
   d) Eddy Current Magnetic Stress Gages (stress)

2) **Core Team has been assembled and biweekly planning telecons are being held to map out FY13 effort and beyond**
   1. WSTF: J. Waller/C. Nichols (modal Acoustic Emission)
   2. LaRC: E. Madaras (Distributive Impact Detection Systems)
   3. GRC: D. Roth (AE analysis applet)
   4. DFRC: L. Richards (multiaxial Fiber Bragg Grating)
   5. MSFC: C. Banks (Fiber Optic Acoustic Emission)
   6. KSC: R. Russell (Eddy Current Magnetic Stress Gages)

3) **Fiber Bragg Grating strain sensors have been shown effective on General Dynamics Composite Overwrapped Pressure Vessel s in many orientations, and on HyPerComp Composite Overwrapped Pressure Vessels in the hoop orientation**

4) **Acoustic Emission analysis applet being developed by GRC to perform unique stand-alone data reduction tasks**
   a) Will handle unlimited file sizes from various equipment vendors (32-bit software)
   b) Performs batch processing enabling tracking of damage evolution
   c) Produces wave statistics commonly used to measure health
      i. Amplitude, rise time, duration, counts
      ii. Energy (Measured area of the rectified signal envelope)
      iii. Spectral density (partial power)
   d) Statistics can be used in cluster analyses to enable key signal characteristics to be quickly identified, e.g. late life, high frequency, high partial power events, flagged as indicators of impending failure

‡ Certified for flight applications and/or ruggedized flight hardware exists

Schedule/Plan/ Milestones:

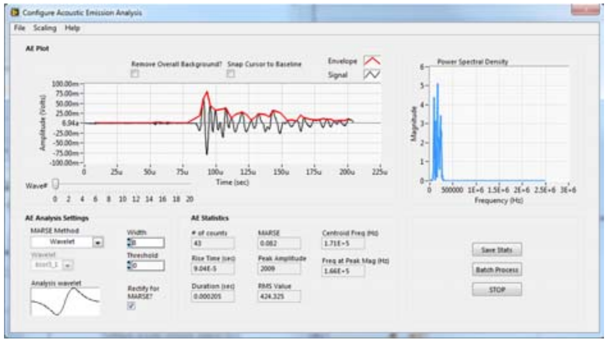
Year	Qtr	DFRC	GRC	MSFC	KSC / LaRC	WSTF
FY12	Q1	Develop of Fiber Bragg Grating sensor methods for embedment in Pressure Vessels	Outline acoustic emission software development direction	Acousto-optic method and sensor development	Eddy Current sensor and method development	Down-select Felicity ratio algorithms; continue acoustic emission method development
FY12	Q2	Feb. 27, 2012: Hydrostatic test of DFRC Bottle 2, instrumented with 800 Fiber Bragg Grating sensors, 6 Strain Gages and 6 Acoustic Emission sensors				
FY12	Q2 - Q3	Pressure vessel-level test of embedded and surface Fiber Bragg Grating arrays	Add WSTF acoustic emission algorithms to GRC Acoustic Emission Analysis Applet	Test selected Fiber Optic sensors and systems	Pressure vessel-level test of Eddy Current sensors	Implement cluster analysis and extensional/flexural waveform analysis
FY12	Q4	Reporting to NNWG. Assess successes and faults for each method. Team vote to decide development continuation.				
FY13		Model validation of pressure vessel Fiber Bragg Grating strain results	Validate new GRC Acoustic Emission Analysis Applet using data from laminate of strand samples	Comparative validation of fiber optic acoustic emission sensors with conventional acoustic emission sensors	Procure Distributed Impact Detection Systems and validate Eddy Current and GRC-WSTF software modules	Develop quantitative Pass-Fail criteria using acoustic emission for actual mission pressure profiles
FY14		Demonstrate integrated Structural Health Monitoring for the above techniques on complex structures (e.g., pressure vessels) as capabilities allow				
FY15		Demonstrate system level testing and pass-fail capability using team-selected NDE techniques using first generation Structural Health Monitoring equipment				

An integrated plan outlining activities from the contributing NASA Centers will be provided in May 2012 that provides specific detail to the overall plan given above. In the meantime, biweekly telecoms are being held to facilitate collaboration between the contributing Centers, to define interim and long term goals, and to allocate future funding accordingly.

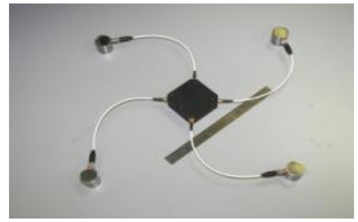
Issues /Concerns:

- The down-selected NDE technologies have varying Technology Readiness Levels. The impetus will be the pull of the technologies to a Technology Readiness Level 6 flight demonstration unit, opening up the possibility of autonomous inspection during service using a real-time wireless Structural Health Monitoring system. However, before this can be achieved, less mature NDE technologies (e.g., Fiber Optic NDE) and factors influencing data quality (composite aging and conditioning) must be better understood. This, in turn, will entail testing at the single tow and composite laminate level, before application to a Composite Overwrapped Pressure Vessel can be made.
- Embedment of NDE sensing technologies continues to be an issue and will likely remain so.

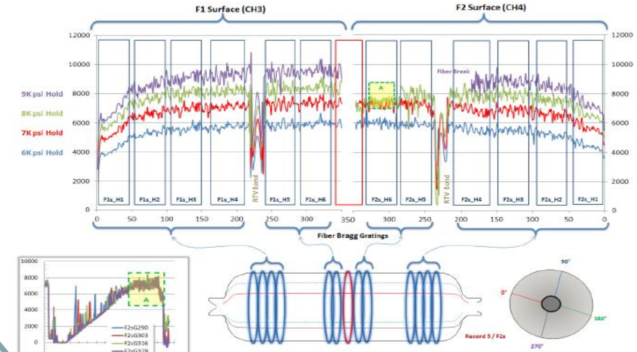
GRC Acoustic Emission Analysis Applet



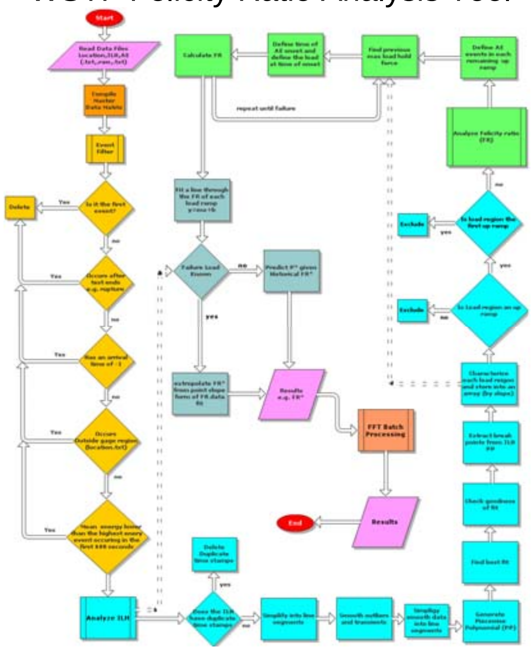
LaRC Distributive Impact Detection System Acoustic Emission



DFRC Multiaxial Fiber Bragg Gratings

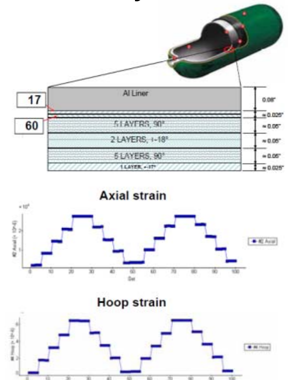


WSTF Felicity Ratio Analysis Tool

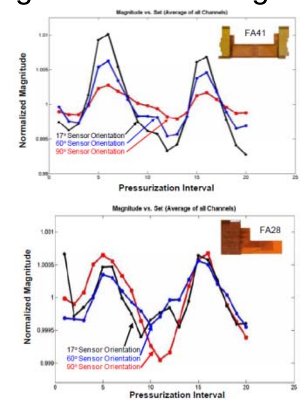


Smart Composite Overwrapped Pressure Vessel

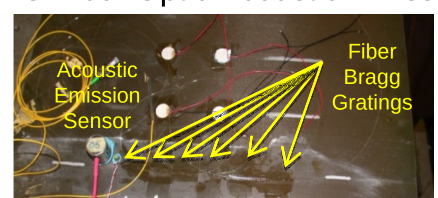
KSC Eddy Current

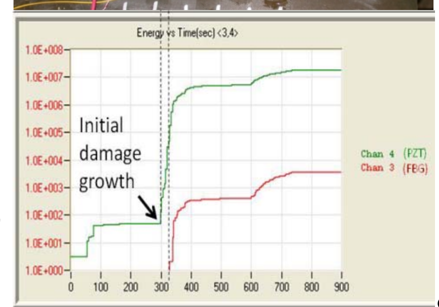


Magnetic Stress Gages

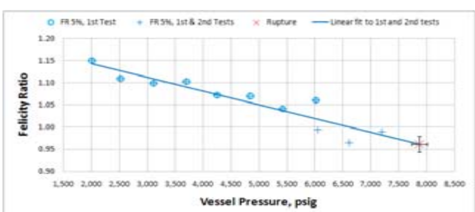


MSFC Fiber Optic Acoustic Emission

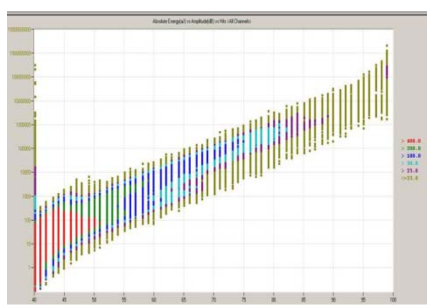




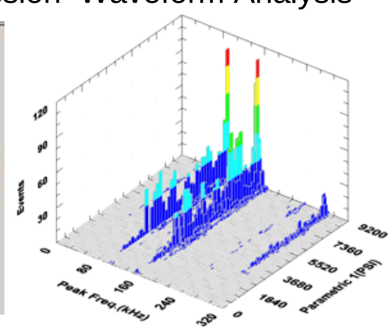
WSTF Composite Overwrapped Pressure Vessel Burst Prediction



Conventional Acoustic Emission



Waveform Analysis



Budget Topics:

NNWG Newsletter Website Operation

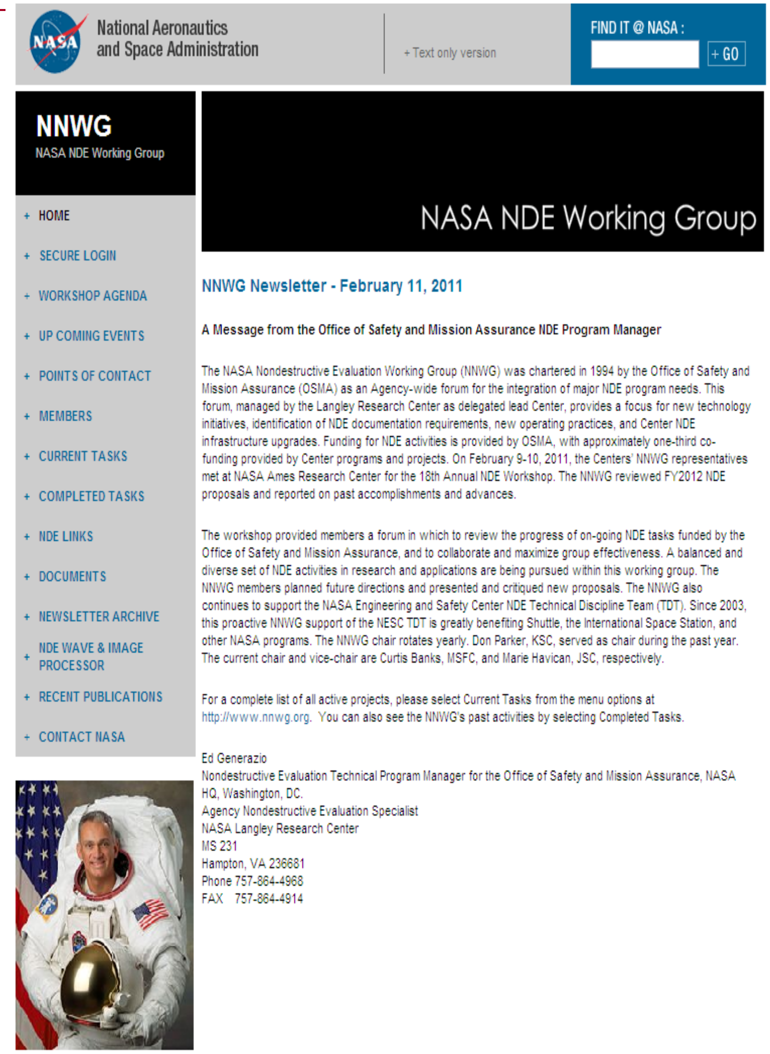
Objectives:

- Provide a highly functional, versatile, and appealing NNWG Newsletter Website at low cost
  - Serve current and anticipated NNWG needs
  - Encourage collaborations with other government and NDE industry
- Accomplish educational outreach
  - Raise awareness: involve students and create interest/excitement about NASA
  - Project oversight (Curator level) by NMSU IT
    - NASA/WSTF has the role of “responsible NASA Official” and interact with local university

Schedule/Plan/ Milestones:

NNWG Events and Website updates on website link:

http://www.nnwg.org/events/index.html



Significant Accomplishments:

- Effective website maintained updated to meet NNWG needs
- Center Task Reports posted and updated updated as received
  - Currently being updated to FY12 tasks
- New NNWG publications and notices added
- Continuing the out-reach to education
- Planning underway to provide updated look and new interviews on the website
- Event and update schedule is on the website at http://www.nnwg.org/events/index.html
- Annual meeting supported (agenda on site)

Issues /Concerns:

- The need for strict Export and ITAR review continues to slow updates and provision of reviewed CURRENT TASK reports are somewhat behind schedule